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Short communication

Influence of seeding rate and row spacing on cuphea seed yield in the Northern Corn Belt

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ABSTRACT

Cuphea (*Cuphea viscosissima* Jacq. X *C. lanceolata* W.T. Aiton; PSR23) is a new oilseed crop adapted to temperate climates that provides a rich source of medium-chain triglycerides. Although prior research indicated cuphea seed yield is not greatly affected by row spacing due to its indeterminate growth, little is known about optimum seeding rate. The present study was designed to test effects of varying seeding rate with row spacing on seed yield. Seed was sown at rates of 4.5, 9.0, and 13.4 kg ha^{-1} in 380, 560, and 740 mm spaced rows in west central Minnesota during 2002 and 2003. Seeding rate did have a significant effect on seed yield and harvest index in 2002, but not in 2003. In 2002, yield under the 9.0 kg ha^{-1} rate was 47 and 19% greater than the highest and lowest seeding rates, respectively. The interaction of row spacing and seeding rate was generally not significant. Cuphea does have good yield plasticity over a range of row spacing and seeding rates. However, results generally indicated that a seeding rate of around 9.0 kg ha^{-1} is near optimum for PSR23 cuphea production and that row spacing less than 740 mm tended to favor greater seed and biomass yields.

1. Introduction

Cuphea is a new oilseed crop whose seed provides a rich source of medium-chain triglycerides. Cuphea grows well in cool temperate climates (Graham, 1989) and its oil can substitute for tropical plant oils [e.g. coconut (*Cocos nucifera* L.)] for manufacturing soaps and detergents, lubricants, cosmetics and other personal care products (Thompson, 1984). Cuphea seed oil can also serve as an engine lubricant with exceptional low temperature pour-point and high temperature stability (Cermak and Isbell, 2004) and it shows promise as a biofuel (Johnson et al., 2007).

Critical to successful commercialization of a new crop is establishing best agricultural management practices. Cuphea lends itself well to row cropping and previous recommendations suggested using row widths that facilitate mechanical weed control as cuphea has been found to tolerate only a few herbicides (Gesch et al., 2003; Forcella et al., 2005). As with most newly domesticated crops, cuphea has an indeterminate plant growth. When grown in the Northern Corn Belt, USA it begins flowering at approximately 500–600 thermal units (°C d) after sowing (Gesch et al., 2002) and continues to flower until killed by frost, although most of its seed set and filling occurs in late summer (Gesch et al., 2005).

Reports of the influence of row spacing and plant population on yields of indeterminate crops like cuphea are somewhat mixed and likely are dependent on both environment and species. Henderson et al. (2000) reported no significant influence of row spacing or plant population on grain amaranth (*Amaranthus* spp.) yields when grown at three sites in North Dakota on 300- and 760-mm rows and populations of 74 000, 173 000, and 272 000 plants ha^{-1}. They attributed this to growth plasticity of plants, but noted that generally greater yields were achieved at the medium plant population on 760-mm rows. Grafton et al. (1988) reported no significant effect of plant population on yields of an indeterminate dry bean (*Phaseolus vulgaris* L.) cultivar, but did find that yields were 52% greater on 250-mm compared to 750-mm row widths, while Alford et al. (2004) showed no influence of 380-, 560-, and 760-mm row spacing on dry bean yields.

When PSR23 cuphea was grown in rows ranging from 130 to 750 mm, Gesch et al. (2003) found no significant difference in yield, although in this study plant population declined with row spacing. This study showed that plants sown in wider rows compensated for yield by branching more and filling more seed capsules per plant. These researchers suggested that cuphea might be more responsive to plant population than row spacing. Sharratt and Gesch (2004) evaluated the influence of row spacing and planting date on cuphea yield, water use, and root growth while keeping plant population constant at approximately 40 plants m^{-2}. They too did not find a significant row spacing affect.

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In the only published report that could be found addressing seeding rate of cuphea, Roath (1998) found that seed yield generally increased with an increase in seeding rate from 1 to 5 kg ha^{-1}, but saw no difference from 5 to 10 kg ha^{-1}. Roath (1998) as well as others (Gesch et al., 2002; Berti et al., 2008) have noted that cuphea possess low seed vigor and seedling emergence in the field. A better understanding of optimum seeding rate for cuphea is needed to maximize seed yields in row-culture. Therefore, the objective of the present study was to address the influence of varying planting rate with row spacing on seed and biomass yield of cuphea.

2. Materials and methods

The research was conducted in 2002 and 2003 at the Swan Lake Research Farm located 24 km northeast of Morris, Minnesota (45°3′N, 95°5′W). Parent soil materials were glacial till. The soil series was a Barnes soil (fine-loamy, mixed, superactive, frigid Calcic Hapludoll). Cuphea (PSR23; Knapp and Crane, 2000) was planted on May 31 in 2002 and May 13 in 2003. In both years cuphea was sown on ground previously cropped in soybean [*Glycine max* (L.) Merr.]. Additional information such as soil characteristics are available (Gesch et al., 2005). Weather data including air temperature and precipitation were collected at an automated weather station within 200 m adjacent to the study site.

The experimental design was a randomized complete block. Each treatment was replicated four times. Treatments consisted of all possible combinations of three inter-row spacings of 380, 560, and 740 mm and three seeding rates of 4.5, 9.0, and 13.4 kg ha^{-1}. Typical seed mass for PSR23 is about 3.0 g 1000^{-1} seed (Gesch et al., 2003). Plot dimensions were 3 m × 6 m. In 2002, cuphea was seeded with a modified solid-stand grass seeder (model PS1572, Land Pride, Great Plain Manufacturing, Salina, KS[1]). Openers of the seeder were blocked to adjust for row spacing and tubes attached to the openers were used to direct the seed into rows. In 2003, a plot drill (model TRM 2200, Wintersteiger, Austria) was used for sowing cuphea. A planting depth of 6.0 mm was used in both years and both seeders were calibrated before planting. Seedbed preparation consisted of chisel plowing the previous fall and harrowing just before planting. Prior to planting, N, P, and K were broadcasted at 112, 13, and 30 kg ha^{-1} in 2002 and 2003 and incorporated into the soil. Trifluralin (*a*,*a*-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine) (1.1 kg a.i. ha^{-1}) was incorporated with the fertilizer for weed control. Additionally, monocot weeds were controlled with sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} (0.3 kg a.i. ha^{-1}). Cuphea is known to be tolerant to these herbicides (Forcella et al., 2005). Hand weeding supplemented further control of broadleaf weeds.

Cuphea was hand-harvested on October 8 in 2002 and September 19 in 2003 by cutting plants near the soil surface from 2-m of row from each of the two center rows of each plot. Plants were air-dried in mesh bags in a greenhouse and weighed before threshing and cleaning seed for yield analysis. Moisture content of seed for yield analysis was 4–5%.

Experimental data were analyzed separately by year because of a significant year effect. A factorial ANOVA with planting rate and row spacing as the main effects was performed using the GLM Procedure of SAS (SAS Institute, 2006). Least-significant difference (LSD) was used to separate treatment effects at the $p \leq 0.05$ level when significant F values ($p \leq 0.15$) were determined by ANOVA.

[1] Brand names are provided solely for informational purposes and do not represent endorsement by USDA-ARS.

3. Results and discussion

3.1. Climate conditions

Average air temperature from planting to harvest was 19.3 °C for both 2002 and 2003 (Table 1). Likewise, the number of accumulated growing degree days from planting and harvest was similar in 2002 and 2003 at 1288 and 1281 °C d (Table 1), respectively. This is near the optimum number of growing degree days of about 1300 °C d reported by Gesch et al. (2005) required for maximum seed yields of cuphea grown in the Northern Corn Belt.

Rainfall from planting to harvest was 361 and 356 mm in 2002 and 2003, respectively (Table 1). July and August of 2003 were unusually dry as the amount of precipitation received was 95 mm below average (Table 1). Because this is a critical period for cuphea flowering and seed set (Gesch et al., 2002), an additional 105 mm of water was applied throughout July and August of 2003 via a portable overhead pivot irrigation unit.

3.2. Seed and biomass yields

Seed and biomass yields were lower in 2002 than 2003 (Table 2). The lower yields in 2002 were likely attributed to late planting (i.e., May 31). Gesch et al. (2002) and Sharratt and Gesch (2004) have shown that delaying cuphea planting beyond mid-May results in reduced seed yield.

Planting rate significantly influenced seed yield and harvest index in 2002 (Table 2), but not in 2003 (Table 3). In 2002, seed yield and harvest index were significantly greater at the 9.0 kg ha^{-1} seeding rate than the 13.4 kg ha^{-1} rate, but not significantly different than the 4.5 kg ha^{-1} rate (Table 2). The lower seeding rates likely resulted in lower plant population. For cuphea, this can lead to increased branching and more seed capsules per plant (Gesch et al., 2003), which often translates to greater harvest index and seed yield. Plant populations that are too high lead to competition among plants for available resources (Adams, 1967) that can result in lower yields. Across all treatments in both years, harvest index ranged from 0.067 to 0.106 and averaged 0.089, which is similar to that reported by Sharratt and Gesch (2004) of 0.080 to 0.087 for PSR23 cuphea grown in Minnesota.

Row spacing had a weakly significant effect on biomass yield in 2002 ($p = 0.15$ for F value) (Table 2) and seed yield in 2003 ($p = 0.16$ for F value) (Table 3). Seed yield for the 560-mm row spacing in 2003 was 26% greater than that of the 740-mm spacing, but was not significantly different than the 380-mm spacing. The unusually dry conditions during July and August of 2003 may have influenced this response. Holshouser and Whittaker (2002) found that soybean yields at two different locations in Virginia only responded to plant population and row spacing when drought stress was a factor. In low stress environments they found no yield response to either factor, but under intermittent drought stress, greater yields favored narrower rows and higher plant populations. They attributed this to plants in narrow rows and at high populations attaining a higher leaf area index (LAI) by late vegetative to early reproductive growth stage on narrow rows. Maximizing LAI as early as possible is crucial for soybean yield because it enables plants to most efficiently capture light, which is even more critical under conditions such as drought that limit dry matter accumulation during vegetative and early reproductive growth (Board and Harville, 1992). This is also likely to be true for cuphea, and Gesch et al. (2003) have shown that by mid-July when plants are in or nearing reproductive development, LAI of plants grown in 380- and 500-mm rows is much greater than those grown in 750-mm rows. Despite irrigating in 2003 in our study, it is possible that high evaporative demand during late summer coupled with cuphea's shallow root system and susceptibility to drought (Gesch et al., 2009) may have led to intermittent periods

Table 1
Climate conditions from planting to harvest in 2002 and 2003. Growing degree days (GDD; °C d) were calculated using a base temperature of 10 °C.

Month	2002[a]				2003			
	Avg. air temp. (°C)	GDD (°C d)	Rainfall (mm)	Dev.[b] (±mm)	Avg. air temp. (°C)	GDD (°C d)	Rainfall (mm)	Dev. (±mm)
May	23.3	13	0	NA	15.6	101	36	NA
June	21.1	334	57	−44	19.1	276	177	76
July	23.4	415	147	54	21.8	366	65	−29
August	20.3	322	90	10	22.3	384	10	−66
September	20.4	202	29	−30	17.8	154	68	NA
October	7.1	2	38	NA	–	–	–	–
Mean	19.3				19.3			
Total		1288	361			1281	356	

[a] Cuphea was planted on May 31 and harvested on October 8 in 2002, and was planted on May 13 and harvested on September 19 in 2003.
[b] Based on the 120-year monthly average accumulated rainfall for the Morris, MN location. Data were collected and compiled from the Univ. of Minnesota West Central Research and Outreach Center, approximately 24 km from the study site.

Table 2
The relationship between planting rate and row spacing in 2002.

	Row spacing (mm)	Planting rate (kg ha^{-1})	Seed yield (kg ha^{-1})	Biomass yield (Mg ha^{-1})	Harvest indexRelative
Interaction					
	380	4.5	357[a]	2.8 b	0.087
	380	9.0	461	3.4 a	0.093
	380	13.4	301	3.1 ab	0.068
	560	4.5	454	3.1 ab	0.099
	560	9.0	426	2.8 b	0.100
	560	13.4	330	3.1 ab	0.078
	740	4.5	290	2.8 b	0.071
	740	9.0	422	2.8 b	0.105
	740	13.4	261	2.8 b	0.067
p-value			0.81	0.12	0.89
Planting rate		4.5	367 ab	2.9	0.086 ab
		9.0	437 a	3.0	0.099 a
		13.4	297 b	3.0	0.071 b
p-value			0.06	0.81	0.13
Row spacing	380		373	3.1 a	0.083
	560		404	3.0 ab	0.092
	740		325	2.8 b	0.081
p-value			0.38	0.15	0.66

[a] Values of individual treatments are means of four replications. Fisher's least-significant difference test was used to separate treatment means. Values within columns followed by the same letter are not significantly different at the $p \leq 0.05$ level.

Table 3
The relationship between planting rate and row spacing in 2003.

	Row spacing (mm)	Planting rate (kg ha^{-1})	Seed yield (kg ha^{-1})	Biomass yield (Mg ha^{-1})	Harvest index Relative
Interaction					
	380	4.5	733[a]	5.1	0.089
	380	9.0	732	5.3	0.087
	380	13.4	780	5.5	0.088
	560	4.5	889	5.3	0.106
	560	9.0	896	5.3	0.102
	560	13.4	762	5.1	0.094
	740	4.5	643	4.6	0.090
	740	9.0	735	5.1	0.091
	740	13.4	640	4.9	0.084
p-value			0.89	0.864	0.98
Planting rate		4.5	755	5.0	0.095
		9.0	788	5.2	0.093
		13.4	723	5.2	0.088
p-value			0.80	0.661	0.68
Row spacing	380		748 ab	5.3	0.088
	560		849 a	5.2	0.100
	740		673 b	4.8	0.088
p-value			0.16	0.201	0.21

[a] Values of individual treatments are means of four replications. Fisher's least-significant difference test was used to separate treatment means. Values within columns followed by the same letter are not significantly different at the $p \leq 0.05$ level.

of drought stress. This might have led to more favorable seed yield on the narrower row spacings.

In summary, there was no strong yield response of cuphea to either seeding rate or row spacing in this study. This is primarily due to cuphea's yield plasticity that results from its indeterminate growth, which is similar to that of other indeterminate crops species such as grain amaranth (Henderson et al., 2000), dry bean (Bennett et al., 1977), and soybean (Weber et al., 1966). Nevertheless, results of the present study indicate that a seeding rate of around 9.0 kg ha^{-1} is probably near optimum for PSR23 cuphea, and when row-cultured, a slight yield advantage may also be realized by seeding in rows no wider than 560 mm. Further research will be needed to target optimum plant population for seed yield of cuphea.

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